Coastal Aerosol Distribution by Data Assimilation

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LONG-TERM GOALS

The long-term goal of this research is to develop an initialization scheme for a multi-dimensional, predictive aerosol model in coastal regions. The initialization scheme will have global coverage and include data gathering, quality control, and data assimilation of the available aerosol observations, including satellite aerosol retrievals, ground-based remote sensing, point measurements, and the previous aerosol forecast. The model will predict the atmospheric aerosols responsible for degradation of EO propagation in regions of DoD interest. Post-processors will calculate parameters for use in strategic and tactical planning, training, and operational activities.

OBJECTIVES

The objective of this program is to investigate, develop, and test aerosol model analysis, initialization, source, and prediction schemes. The ultimate goal of the program is to develop an aerosol data assimilation and prediction system based on observations, aerosol process models, and meteorological models.

APPROACH

The approach to the problem of aerosol and Electro-Optical (EO) extinction prediction follows that used in numerical weather prediction, namely real-time assessment and first-principle modeling. A predictive model requires the initial spatial distribution of the aerosol field including composition, concentration, and size distribution. Sensors and retrieval techniques exist for obtaining the aerosol optical depth (AOD) and some information about particle size. The remotely sensed aerosol properties typically are vertical integrals and are generated at horizontal resolutions ranging from one kilometer to one degree. An objective analysis method is being devised to merge these disparate 2-D distributions with point measurements and the model's first guess field to produce a three-dimensional description of aerosols. The first-principle modeling approach has been used to develop a predictive model of tropospheric aerosols. Given the analyzed initial condition, the future distributions of those aerosols important to EO propagation, namely sulfate, dust, smoke, and salt are predicted numerically. The predicted model variables are then converted to the bulk optical parameters required for EO calculations, based on the appropriate optical properties.

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14. ABSTRACT
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WORK COMPLETED

A global predictive model of tropospheric aerosols has been developed over the past several years. There is an ongoing effort to improve to the source functions, validation techniques, and product distribution. With its global, continuous coverage, the Navy Aerosol Analysis and Prediction System (NAAPS) is invaluable in filling the gaps in observations of aerosols and visibility and in satellite observations and extends our understanding of aerosols and their impact on Navy operations.

The original TOMS/USGS dust source database has been updated using the NRL high-resolution dust source database. This new database was developed for use with the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®[1]) dust forecasting in Southwest Asia and East Asia and has a horizontal resolution of 27-km.

In collaboration with NASA/GSFC, the SO_2 source database is also being upgraded. The original GEIA (Global Emissions Inventory Activity) database will be replaced by either the AeroCom (Aerosol Model Comparison) or ACACIA (A Consortium for the Application of Climate Impact Assessments) SO_2 databases. These two databases were developed within the past 5 years and reflect changes in the emission rates in East Asia brought about by the rapid industrialization of that region. Collaboration with Scripps Institute of Oceanography and the University of Warsaw has led to the addition of a sea salt component to NAAPS. The single-bin implementation will provide improved estimates of visibility and optical depth over the oceans, particularly over open-ocean under strong wind conditions.

A continuous simulation of aerosols for the globe for the years 1997 – 2005 has been carried out using the current NAAPS model. This simulation has produced a consistent dataset that will be utilized for retrospective studies of atmospheric phenomena and used for validation of NAAPS.

An NPS program to retrieve aerosol optical depth (AOD) from AVHRR and MODIS satellite data was developed and has been applied to the Arabian Gulf and Mediterranean Sea. Retrievals of AOD are carried out each day. Comparisons are being made with other MODIS-based AOD algorithms. From these datasets, we will develop error covariance matrices for MODIS, AVHRR, and AERONET for use in aerosol data assimilation, in conjunction with the ONR 6.2 AeroMR work unit.

We are participating in the Dust Model Intercomparison Project (DMIP) along with six other dust-modeling groups from China, Korea, Japan, U.S.A., Canada and Malta. The program is comparing various aspects of the model simulations of Asian dust storms for two two-week periods during 2002. The important processes include mobilization, mixing, transport and removal. Participation in the program includes access to validation data.

NRL researchers continue to interact and collaborate with outside researchers through the use of NAAPS data for explaining various aerosol transport phenomena around the world. These collaborations result in a better understanding of the atmosphere, an improved NAAPS model, and peer-reviewed publications and conference proceedings.

[1] COAMPS is a registered trademark of the Naval Research Laboratory.

RESULTS

The evaluation of the upgrades to the dust and SO_2 source databases is underway. Comparisons are being made between the original simulations, the new simulation, and the available data, which include AERONET sun photometers, IMPROVE network data, surface concentrations, visibility, and satellite retrievals. Final results and conclusions are not yet available.

In collaborative work with the Colorado State University and the University of Warsaw, North American dust production is being investigated and compared with that from East Asia. The latter dominates large areas of the U.S. in the spring, but North American sources produce the highest concentrations in other seasons, though over more localized regions. Further studies will lead to an improvement in the dust source database for North America.

NAAPS was used to forecast dust during the United Arab Emirates United Aerosol Experiment (UAE^2). During the mission, NAAPS underestimated the background aerosol concentration: the measured optical depth seldom fell below 0.3 yet NAAPS AOD was usually below 0.3. Analysis of the field measurements shows that much of the summertime aerosol is anthropogenic. The upgrade in the SO_2 source database is expected to improve this situation through increased emissions. NAAPS does perform better in winter and spring when synoptic forcing is stronger.

The DMIP program found that NAAPS and COAMPS produced results that were in the middle of the distribution of results from the group of models. We have identified some errors in the dust source database for East Asia and have made corrections to the database. The intercomparison of the dust models revealed differences in all aspects of the dust models: dynamical forcing (wind strength), the source parameterization, and the transport processes. This has led us to begin a study of the dynamical forcing term, as it is the most fundamental of all processes.

IMPACT/APPLICATIONS

Presently, NAAPS runs in a predictive mode and can help to satisfy the Navy's long-term goal of a predictive capability for aerosols and EO propagation. This research also provides tools for the 6.1 and 6.2 aerosol research communities and the academic community. NAAPS data continues to be used in interactions with research community appearing in peer-reviewed and conference papers. Over the past years, collaborations have been initiated between NRL and University of Miami, University of Wisconsin, University of Alabama, NASA/GSFC, Chinese Academy of Sciences, University of Warsaw, MBARI, Université de Sherbrooke (Quebec), and others. NRL's continued participation in field programs will give us further opportunities for collaboration and access to important validation data.

The improvements in aerosol and visibility forecasting for CONUS will be valuable in designing mitigation strategies by DoD bases in the Southwest United States. The simulations can be used to determine which exceedances of EPA air quality standards are due to non-DoD sources. As an example, NAAPS simulations were used by Jaffe et al. (2004) to show that ozone exceedances in Washington State from 1996 – 2004 were attributed to Siberian smoke. We found a strong correlation between many of the worst conditions and incursions of Siberian forest fire smoke, emitted as much as a week earlier. The daily smoke sources provided by the Fire Locating and Modeling of Biomass Emissions (FLAMBE; NASA and ONR funded) make these simulations possible. Similarly, Honrath et al. (2004) used NAAPS to attribute interannual variations in CO and Ozone over the Atlantic Ocean

to interannual variations in long-range transport from N. America and Siberia. Concentrations measured in 2002 showed little variation while those from 2003 had large pulses imposed on the background values. NAAPS showed little forest fire smoke over the region in 2002 and numerous large events in 2003.

The improvement of the dust source database should improve the operational dust forecasts for East Asia and Southwest Asia and the regions downwind of those sources.

TRANSITIONS

NAAPS has been ported to FNMOC and is running in beta test mode as of September 2005. Subsequent improvements to NAAPS (as developed in this work unit) will be transitioned to FNMOC via 6.4 funding provided by PMW-180.

RELATED PROJECTS

The NRL 6.1 base *Atmospheric Physics* and the NRL 6.2 base *Improved COAMPS Land Boundary Layers* (includes COAMPS aerosol modeling) use NAAPS data and products and the satellite retrievals for investigations and validation. The improvements to NAAPS and the implementation of NAAPS and FAROP at FNMOC are supported by PMW 180 6.4 *Large-scale and Mesoscale Aerosol Forecasting*. This funding also supports development and generation products for use by the fleet.

PUBLICATIONS

2004, Jaffe, D., I. Bertschi, L. Jaeglé, P. Novelli, J. S. Reid, H. Tanimoto, R. Vingarzan, D. L. Westphal, Long-range transport of Siberian biomass burning emissions and impact on surface ozone in western North America, Geophys. Res. Lett., 31, L16106, doi:10.1029/2004GL020093 [published, refereed]

2004, Honrath, R. E., R. C. Owen, M. Val Martín, J. S. Reid, K. Lapina, P. Fialho, M. P. Dziobak, J. Kleissl, and D. L. Westphal, Regional and hemispheric impacts of anthropogenic and biomass burning emissions on summertime CO and O3 in the North Atlantic lower free troposphere, J. Geophys. Res., 109, D24310, doi: 10.1029/2004JD005147 [published, refereed]

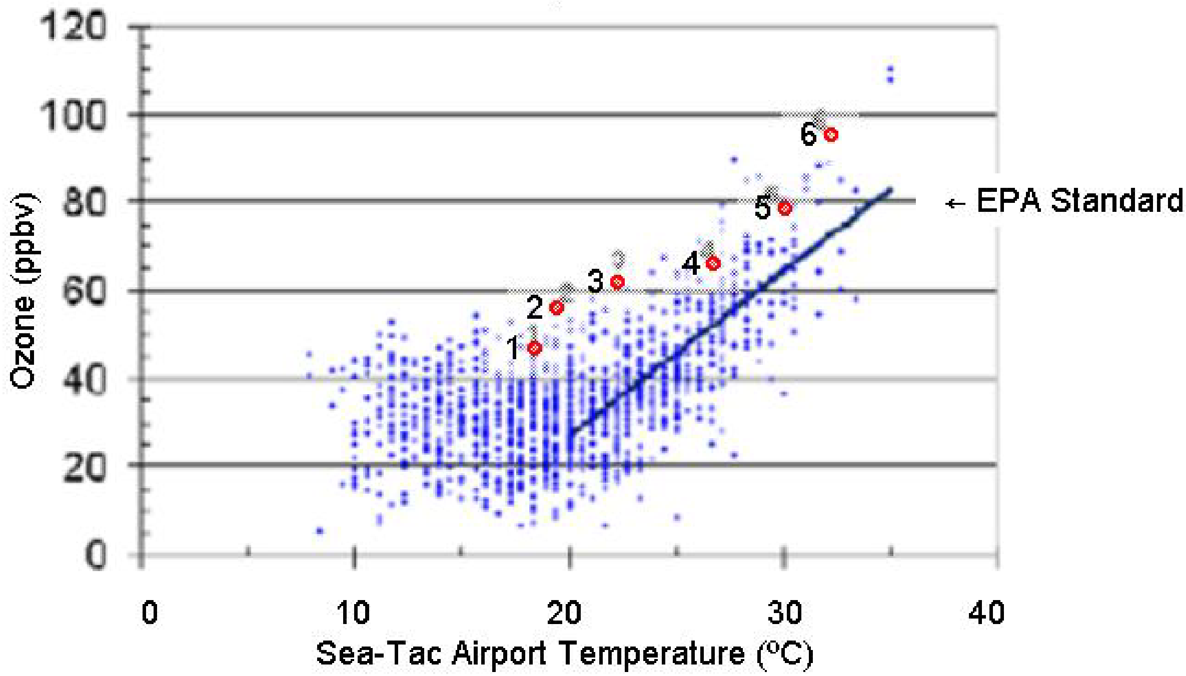

Figure 1. Ozone concentrations (in ppbv) at Enumclaw, WA, as a function of air temperature at Sea-Tac Airport, WA showing near linear relationship at temperatures above 20 degrees centigrade. At these temperatures, six of the highest ozone concentrations occurred when Siberian forest fire smoke was present, as determined from NAAPS simulations. (Jaffe et al., 2004).

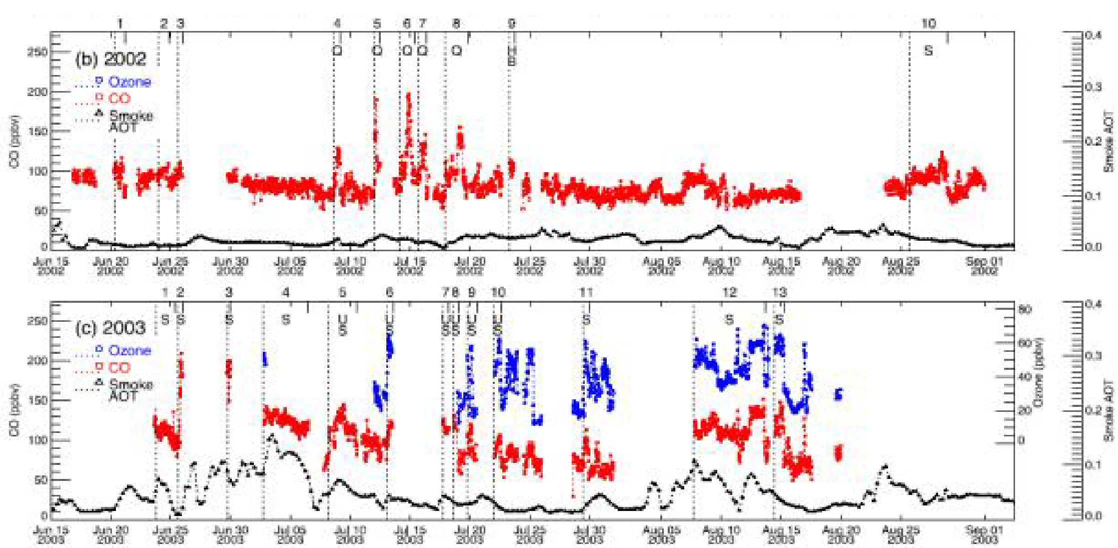

Figure 2. Time series of measured CO, measured O3, and NAAPS/FLAMBE smoke aerosol optical thickness (AOT) each summer. CO is plotted with red squares, ozone is plotted with blue circles, and smoke AOT is plotted with black triangles. (Ozone measurements are not available during summer 2002, and are missing during some periods in 2003.) Source-fire regions for biomass burning-impacted periods are identified near the top of each plot: S, Siberia; Q, Quebec; HB, Hudson Bay; US, the western United States.